Mathematical Modelling and Simulation of Chemical Engineering Process

Professor Doctor. Sourav Mondal
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture 40

Heat exchanger network design – pinch analysis

Heat exchanger networks are very important in any process industries. Why? Because normally our heat exchanger does not work (I mean) standalone, there will be several heat exchangers which are present in a process plant and normally the question comes that whether are we are using these heat exchangers in an optimized way.

For example, if in one of the exchangers you try to cool down a liquid and there is a possibility of other exchanger where you want to heat the liquid, then one of these liquids can be used for heating another one can be used for the cooling and essentially there will be some part of the heat still left from the hot fluid and there can be also some part of the heat deficit for the cold fluid which can be matched with one another in network or another exchanger present in the network.

So, heat exchanger network or this configuration of this network is very, very crucial and in the current age of so much of emphasis being made on energy as well as energy conservation or optimal utilization of the energy proper design of the heat exchanger network is very very essential. So, in this class and also in the next class, we will talk about that what are the some there are some criteria, there is something called as the pinch analysis.

So, what do we mean by this pinch point and then how does it affect the network design and essentially, if in a series or if in a system you have multiple hot and cold streams, we and then how you can place the exchangers effectively, so that the overall utility is in the process is minimized or the utility loads in the process or in the plant during this you know, this whatever division that you are working in is actually minimized.

So, synthesis of the exchanger network is very important and this is something which is very useful considering the current energy scenario in the industries. So, you do not want to lose any bit of energy and we want to utilize as much as possible by exchanging it. So, exchanging energies that could be utilized by exchange is the best way of energy recoveries in the process.

So, there is always a possibility that there will be more than one I mean, there will be some hot stream and there is some cold stream.

So, hot streams needs to be cooled down and cold streams needs to be heated up. So, in the process, this heat exchanger plays a role so and it may happen that the heat or the enthalpy available with one of the streams or entropy requirement of one of the streams the cold streams are not matching and then you can play some other network and you can get I mean heat exchanger connections in a network handling multiple fluids and in multiple process streams so, that this energy recovery is optimized.

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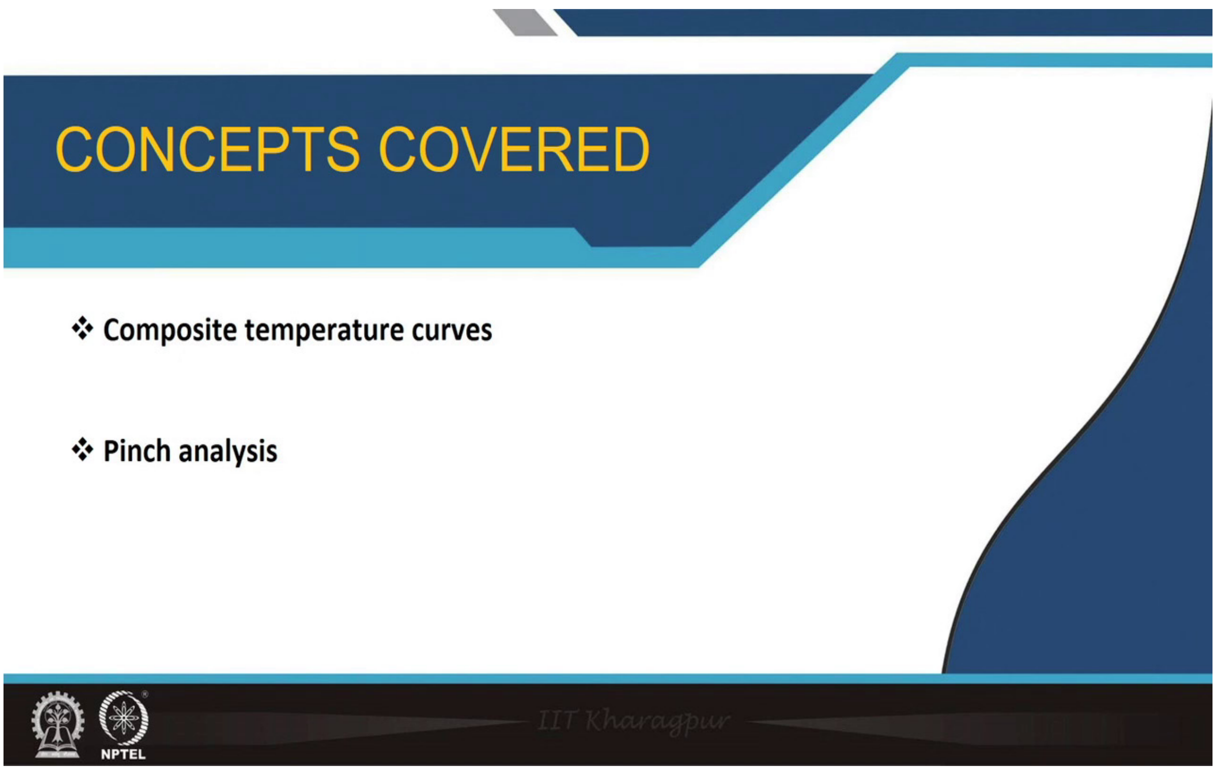

Now, let us look into in this class we will focus mostly on how we can prepare the composite temperature curves if there are more than if there are multiple processes streams, and then from there we will try to interpret what essential do we mean by this pinch point temperature.

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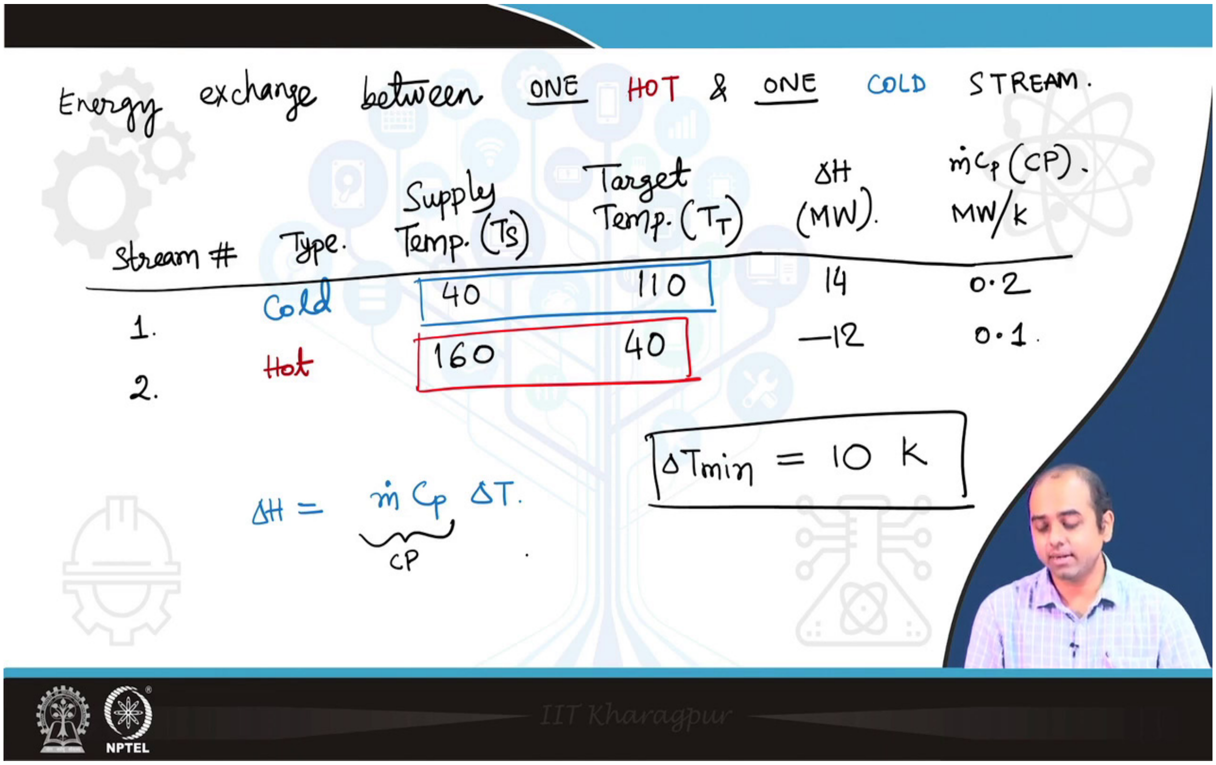

So, let us look into a scenario where we have say only one hot and one cold stream in the process. So, let us look into that scenario first and we will move to two streams in the process. So energy exchange between one hot and one cold stream. So, generally we try to write the hot or marked the hot in red and cold in blue color, just the convention.

So, now let us say this is our let us write down the stream tax like the stream 1 and then we have stream 2 as far as the type is concerned we write stream 1 as cold, sorry stream 2 as hot and stream 2 as cold, why? Because the hot stream the hot stream has heat that can be delivered that can be supplied it is essentially needs to be cooled down.

So, it has excess heat in it. So, let us say the supply temperature, sort of inlet temperature and then you say the target temperature or the exit temperature from the exchanger amount of heat available delta H value with the hot and cold stream. So, for the hot stream, let us say the temperature is 160 that we supplied and the target is we want to reduce it to 40 and the delta H is specified as minus 12, so it has excess minus 12 megawatts.

It has excess of, I mean, it has energy which can be released, so this stream can provide energy to heat up another stream. So, in the case of the cold stream it is available at 40 or the supply temperature is 40 but we want to raise this temperature to 110 for use it in a subsequent process. So, the delta H value is 14. So, it means it requires 14 megawatts of energy, whereas the cold stream that we are having, sorry, the hot stream that we are having here can supply up to 12 megawatts of energy.

So, this clearly shows that if we try to exchange them theoretically up to 12 megawatts of energy can be exchanged so that the hot stream can be cooled down and it will release all the 12 megawatts of energy which can be gained by the cold liquid. So, this is the temperature drop for the hot stream and this is the temperature drop for the cold stream.

So, but the energy is not matching, so at least 12 megawatts can be exchanged and further we need 2 megawatts of hot utility to heat up the cold liquid that is what theoretically we get. So, whatever exchanger we design at least up to 12 megawatts of capacity that it should be able to provide and that forms the basis of the design of the heat exchanger as well as the heat exchanger area that is required and that will lead to calculation of the number of these tubes in the heat exchanger, size of the shell, number of passes, etc., and everything.

So, this delta H whatever we got is equivalent to m dot Cp delta T m Cp delta T m dot is the mass flow rate or you can write also Cp. So, generally in the process industries you club this m dot into Cp as capital CP is just the industry standard nothing to do with the calculations. So, instead so this from delta H and knowledge of the temperature drops I can also work out this my m dot Cp or sorry m dot Cp or this capital CP and this is in terms of megawatts per Kelvin.

So, for the case of this cold fluid this comes to around 0.2, so this is higher specific heat, that is obviously we can realize because even with more amount of energy required the temperature the starting temperature is 40 but it is still not raising to not much it is 110, had it been both the same liquids and same flow rates then with the same for the same amounts of energy or the amount of energy is more than it would have heated more beyond 160, that is not the case.

So, that is clearly understood because either the flow rate is more or the specific heat capacity is different. So, in this case, please note that, whenever we are trying to design the heat exchanger, we have to maintain certain minimum temperature difference that is what we call this delta mean, otherwise the exchanger will not operate if the temperature difference does not exist at any point in the exchanger in the tube that there has to be some delta.

I mean, it has to be there and as far as the International ASME standard at least 10 Kelvin that needs to be at least maintained in the exchanger for effective heat transfer. Otherwise, if this is close to 0, then essentially this will be the heat exchanger area will be in infinite. So, at least some minimum temperature drop has to be specified industry standard or the international standard is 10 Kelvin.

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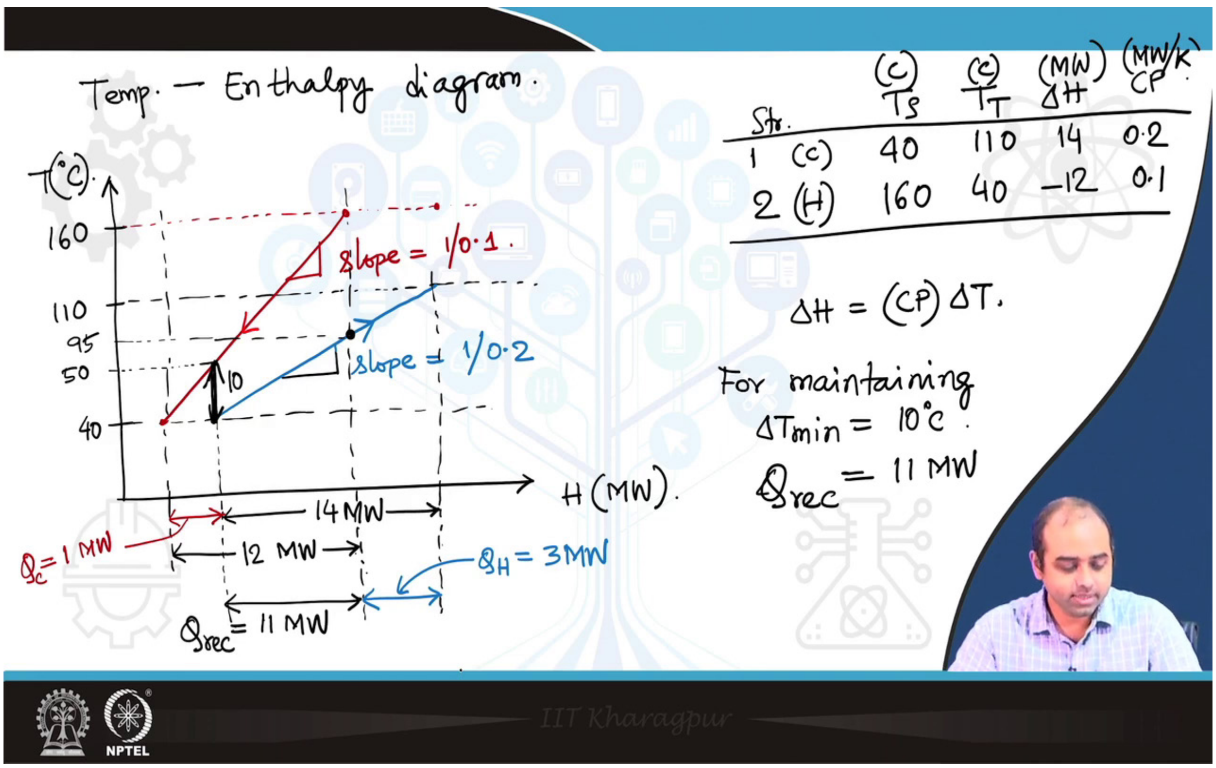

Now, if we try to draw the temperature enthalpy diagram and plot these curves temperature enthalpy diagram, let us see how does it look like. So, we have the stream 1 and 2 and this one is of course cold and 2 is hot. So, the supply temperature is 40 in this case it is 160 and the target temperature is 110 and this is 40, delta H value in terms of megawatt.

This is in terms of Kelvin, this is in terms of Kelvin, not Kelvin, I mean, degree centigrade, sorry. And this is in terms of megawatt, this is 12 so that is the cold liquid, please note that when delta H is negative it is representing the hot liquid and CP is also something we have calculated as megawatt per Kelvin.

So, that is 0.2 and this is 0.1 this is the information we got from the streams. Now, let us try to draw this and temperature enthalpy diagram. So, the basic formula is delta H is equal to Cp delta T. So, in temperature enthalpy diagram, when the slope is just inverse of this CP. So, in the x we generally write the enthalpy and the y we write the temperature.

So, this hot stream whatever we are having in this case, this hot stream that whatever we are having it is let us mark the temperatures first. So, this is 40 degrees then let us say this is 110, let us say this is 160, so the cold stream is getting heated up from here to up to like this up to 110. So, the slope of the cold stream, better I should draw it in blue that is the cold stream.

So, the slope is one by Cp or in this case it is 1 by 0.2 and in the case of hot stream it also starts from, sorry it actually starts from 160, so let us draw it. So, let us say it starts from here something like this it starts from 160 and goes down to 40 and the cold one gets heated up from this 40 to 110. Now, let us say that these whatever these two streams we are talking about, sorry not to go like this better let me draw a generic equation because the slopes are different.

So the slope for this one is equal to 1 by 0.1 for this hot stream and you can understand that whichever has higher CP will have a smaller slope, in this case the cold stream has higher CP now the slope is less. So, what you can interpret from this temperature and enthalpy diagram? So, this whatever the amount of energy that it is having from here, in this case till the point here this entire part here is 12 megawatts, please do not make it minus 12 megawatts.

So, this is this is so this x axis is in absolute scale, so we are only interested in delta H. So, you can start from any point and you can draw this, I mean on the x axis you can choose any point and with the particular slope, so the two fixed points in the y axis which is 40 and another is 160 for the hot curve.

So, you choose any point in the x axis and you choose up to 12 megawatts I mean whatever slope you decide it will give you almost 12 megawatts of a difference and intentionally I have drawn this curve before the, this cold curve so that there is some temperature difference we can understand. Similarly, for the case of the cold fluid, this is the temperature drop this is a temperature difference. So, this we are having as 14 megawatts for the cold side fluid.

So, clearly you can see that, if I am supposed to maintain these 10 degree of difference, I mean minimum 10 degree of difference you have to maintain for the heat exchanger to work, then this simply suggest that this is even really understand that this is the minimum point, is not it? This is the minimum point. So, these points suggest that at least this point has to be 50 degrees.

If this is the case then rest in the curve, I mean both the curves this will be I mean this whatever the temperature difference we are having is more than 10 degrees, so the minimum area for this curve or a minimum point for this curve that has to be maintained 10 degrees is at this location, is not it? This the difference has to be 10 degrees, otherwise the heat exchanger will not work.

And this what is the natural consequence that we see here is that if this is the case, then there is a certain part of the energy available with beyond this temperature you cannot cool the hot liquid using this cold liquid. So, below 50 degrees from 50 to almost 50 to 40 degree in this part.

So, this is the zone this is the zone where heat transfer cannot happen with the cold liquid and you can clearly work out the slope is, I mean the CP value is 0.1 and temperature drop off at 10 degrees. So, this part is I can write it as a Qc and this is equal to 1 megawatts, is not it?

Similarly, on the right hand side, you see that there is a point and if you work out carefully or if you calculate carefully, you will see that beyond this point for this slope, I cannot heat the cold liquid further because there is no availability of the hot curve beyond that point.

So, this point is around 95, so please excuse my drawing. So, this is the region where the hot fluid cannot supply any heat to the, to heat up the cold liquid. So, from 95 to 110 up to this much this almost 15 degrees, the cold temperature cannot be heated and the cold liquid or the cold fluid cannot be heated by the hot fluid.

So, the deficit in this part is around this is what we called as QH because that has to be heated up. So, there is a hot utility you need to heat up the cold liquid and this is around 3 megawatts because the cold liquid has CP of 0.2 and 15 degrees temperature rise. So, you get around 3 megawatts. So, essentially you see that in this entire picture you see that only this part of the fluid that from here till here.

So, this part of the fluid that is from 50 degrees for the hot I mean for the cold sorry, for the hot side liquid it is from 50 degrees to 160 degree, in this temperature zone the heat exchanger can work and that for the cold side fluid it is from 40 to 95 it can work. So, either way this means around 11 megawatts of energy which can be utilized. So, this is like Q which can be recovered I should say, which can be utilized by these two streams.

So, even though there is availability of almost using all 12 watts, sorry 12 megawatts of energy from the hot fluid since we have to maintain we have to maintain a minimum temperature drop of delta T minimum of 10 degrees so for maintaining delta T minimum of 10 degrees you can see that the heat that can be recovered or exchanged is only 11 megawatts even though there is a possibility of 12 megawatts of energy that can be utilized, but it is not possible practically.

And what about the remaining that for the hot utilities which means heating up after cold liquids additional three megawatts of energy have to be supplied in the form of a heater to heat up this cold liquid from 95 degrees 210 degrees. Similarly, 1 megawatts of energy has to be supplied to the hot or needs to be taken out from the hot fluid by using some cooling systems or some refrigeration, whatever cold utilities you think have to reduce its temperature from 50 to 40 degrees.

So, this is for something what happens, we see that even though there is a total possible energy of almost 12 watts can be used, but we cannot use that, so only 3, sorry 11 megawatts of energy can be utilized in this case.

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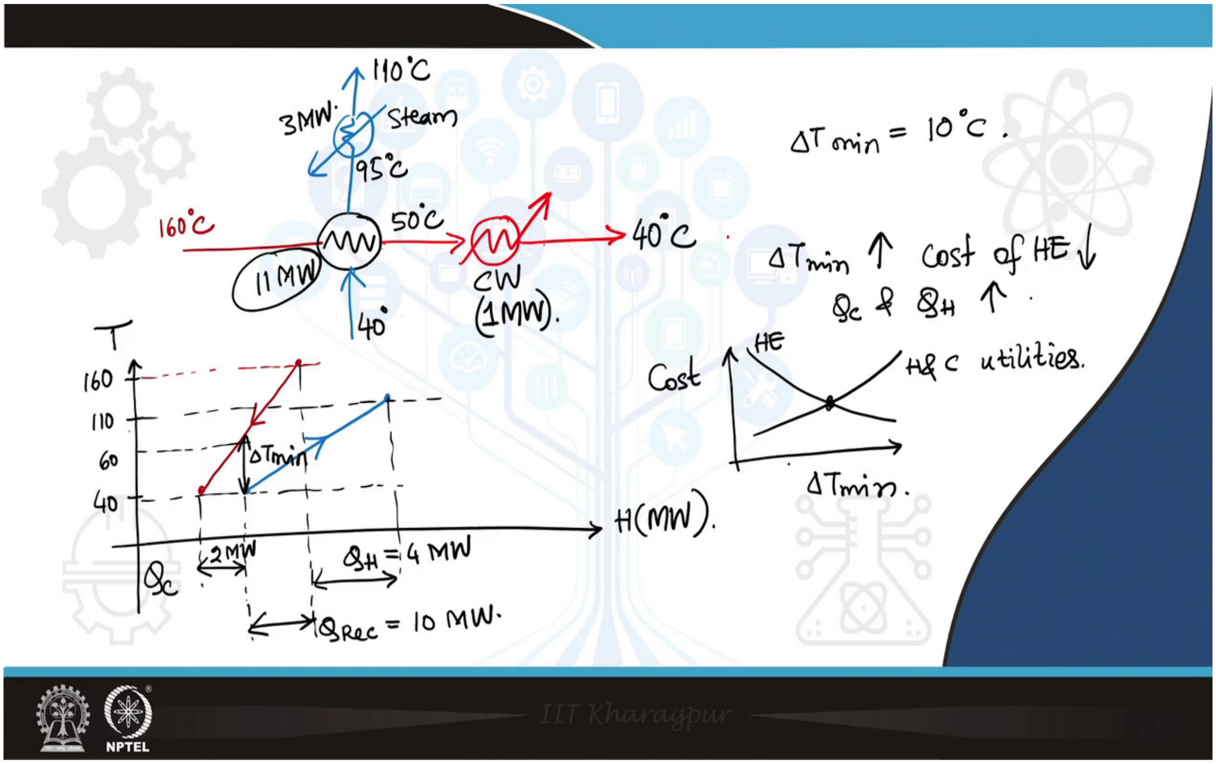

So, if I try to draw the sort of whatever this process scheme, so let us say I have cold, sorry hot site fluid, let me try to give you a more industry type diagram. So, let us say this is my hot fluid, which is coming at 160 degrees. So, here I can apply whatever this heat exchanger, this is a heat exchanger. So, let me draw this heat exchanger in black, is the heat exchanger, then the hot liquid goes after the heat exchanger it goes to a cooler and finally it reaches to 40 degrees.

So, what are the temperature, so after the heat exchanger, it comes to 50 degrees and after the cooler it comes to 40 degrees and in this heat exchanger, we have this cold fluid line. So, the cold fluid line goes in there it exchanges heat and then finally we have to arrange for heater and then it finally goes out.

So, originally it was 40 degrees after the exchange it reaches 95 degrees and then finally using the heater or using a steam heating or whatever, it goes to 110 degrees. So, this energy requirement or energy supplied by this hot system or whatever steam that you can think of is around 3 megawatts of energy and in this cooling water or this cooling system, almost 1 megawatts of energy is supplied and this heat exchanger is providing or exchanging 11 megawatts of energy. So, this is for delta T minimum of 10 degrees.

So of course, you realize now that if we are having let us try to also work out what happens when we have delta T minimum of 20 degrees and then the thing will be more clear to you. So, this is let us mark the temperatures 40 degrees and then we have let us say 110 and 160, so for the case of cold liquid it is from 40 to 110 and for the case of the hot liquid, it is from 160 to 40 something like this dropping down from 160 to 40.

And we have said the minimum temperature drop should be 20 degrees, so let us say this is the point of the minimum delta T min. So, if it is 20 degrees this point would be 60 degrees. So, if you work out the numbers here in this case, we will see that this is the part where it cannot I mean the hot liquid cannot be cooled by exchanging heat with the cold liquid. So, in this part this part turns out to be this QC is almost 2 megawatts.

So, this is the temperature this is the H in terms of megawatts and similarly, this part that is QH that is 4 megawatts and the amount of energy that can be exchanged effectively in this overlap zone, which is something we call as Q recovery is only 10 megawatts. So, if so as you can see that in this case the delta T minimum and if we are rising delta T minimum from 10 to 20 degrees, so if I am rising this delta T minimum from 10 to 20 degrees, let us also think that the heat exchanger recovery is reducing and we are increasing our cold and the hot utilities.

So, the cold utilities in from 1 megawatts it has increased to 2 megawatts and the hot utility has increased from 2 megawatts to almost from 3 megawatts it has increased to 4 megawatts. So, essentially, we can realize that as we increase the delta T minimum, the cost of heat exchanger reduces because of course the amount of energy to be exchanged in the heat exchanger will be reduced and in that process the cost of the exchanger will go down, because the size capacity, etc., will go down, but the hot and the cold utilities, these costs will increase.

So, if I try to plot down the cost in total the cost of the process with respect to this delta T minimum, so as I am increasing my delta T min, my heat exchanger investment reduces, but my cost of the hot and cold utilities raises. So, there has to be a trade off from the cost perspective, there has to be a tradeoff, it is not that if we always we should try to have more and more amounts of energy exchange.

So, that means the cost of the exchange will be on the rise, which is not something very desirable also because there is a lot of capital investment and also maintenance issues. But again, this will increase the hot and cold utilities cost. So, there has to be optimization between these two, but in the current energy scenario, since the energy cost becomes too high, and it is most likely going to exceed or supersede the, cost of investments made in the heat exchangers.

I mean going down, going for higher capacity exchangers are bringing down the delta T minimum from 10 to let us say little bit lower value 7 or 8 though it is not the industrial practice can effectively reduce the hot and cold utility cost. So, that is something we need to think over and this is the scenario when we try to draw this temperature enthalpy diagram.

So, in the next class we will talk about a composite curve when you have more than one hot stream and more than one cold stream and from there we will try to estimate or get an idea about what do we mean by the pinch points temperature in this case. So, I hope all of you liked and got a flavor of this how the temperature enthalpy diagrams are essentially constructed.

And in the next class we will go we are going to build on this temperature enthalpy diagrams which is in the next week of course, we will see that how we can draw a composite temperature enthalpy curves, and from there we will go on deciding what we mean by the pinch point temperatures. Thank you, see you in the next week.